The spectacular monumental ensemble of the Wazir Khan Mosque in the Walled City of Lahore was built in 1634 during the reign of the Mughal emperor Shah Jahan. Its endowment then comprised the congregational mosque, an elaborate forecourt, a serai, a hammam, a bazaar, and a special bazaar for calligraphers and bookbinders. The mosque, the calligraphers' bazaar, and the hammam still stand, while the other elements have disappeared—victims to Lahore's turbulent history over nearly four centuries since the original dedication. What remains is increasingly in need of care and attention.

Over a two year period starting in 2009, the Historic Cities Programme of the Aga Khan Trust for Culture, through the Aga Khan Cultural Service - Pakistan, conducted a baseline documentation of the monument and its surrounding areas. This volume contains the results of this work and presents an assessment of the organisational, technical and financial requirements for the conservation of the mosque as well as the revitalisation and enhancement of its surrounding context.

The Trust has been actively engaged with the Punjab Government in the conservation of the urban fabric of the Walled City of Lahore and has, since 2007, collaborated in urban rehabilitation and infrastructural improvement efforts in the neighbourhood of the monument.
USE OF SPACE WITHIN THE MONUMENTAL COMPLEX

Although the original Waqf deed of the Wazir Khan Mosque stated the desired uses of the various rooms within the mosque complex, little regard is now paid to it. The rows of hujras on the northern and southern side of the courtyard were intended for meditation and teaching, but are now largely used to house services relating to electricity, gas and water, as storage for prayer rugs and electrical items, and as living rooms for various members of the mosque staff. A number of these rooms, particularly those used for the storage of items not often required and where debris and detritus from previous repair operations are also kept, are locked and are rarely accessed.

On the east side of the courtyard, all the rooms are used for storage and all are either rarely or never opened.

In the prayer chamber, although all areas are accessed on a daily or weekly basis, the chambers at the north and south side are used for the storage of pedestal fans which are taken out when required during prayer times. Being unwieldy, the shifting of these fans has caused considerable damage to the walls decorated with fresco work.

The original deed stated that the shops located within the Calligraphers’ Bazaar were dedicated exclusively to book binders and calligraphers. However, the majority of these spaces are now used by the Auqaf or Archaeology Departments either as storage or as offices. And additionally, a medical dispensary run by the Auqaf exists on the northern side of the bazaar. The shop located at the north-east end and the shop located at the south-east end of the bazaar are currently occupied by a key maker and rubber handle maker respectively.

On the mosque’s external façades, shops were integrated on the eastern and northern sides in the original design. However, rising street-levels within Wazir Khan Chowk and Kotwali Bazaar have rendered these original rooms as impractical for anything other than semi-underground storage, and accordingly, particularly on the Kotwali Bazaar side, shop owners have extended outwards to provide more usable space. On the northern side, shops are mainly in the fabric, garment, bag or crockery business, whilst on the east side, metal workers predominate, using the Chowk as a work area in the open.

In the rest of the Chowk, the original right of way marked by the concerned Patwari from the Revenue Department in February, 2010, is shown on page 193 as a red line. The original space of the Chowk is no longer discernable, as most of the buildings contemporary to the mosque have been demolished and the new ones extended into the Chowk. Most of these shops (including along the angular pathway) are in the fabric or garment business, but in the Dina Nath Well area in particular there is a large number of food stalls with outside seating benches.

The following plans show use of space within the mosque, at street-level on its northern and eastern sides and within the Chowk, as well as how frequently the mosque’s spaces are accessed.
# LEGEND FOR USE OF SPACE AT LEVEL 0

<table>
<thead>
<tr>
<th>EAST SIDE</th>
<th>NORTH SIDE</th>
<th>WEST SIDE</th>
</tr>
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<tbody>
<tr>
<td>S1</td>
<td>N1</td>
<td>W1</td>
</tr>
<tr>
<td>S1a</td>
<td>N1a</td>
<td>W2</td>
</tr>
<tr>
<td>S2</td>
<td>N2</td>
<td>W3</td>
</tr>
<tr>
<td>S2a</td>
<td>N2a</td>
<td>W4</td>
</tr>
<tr>
<td>S3</td>
<td>N3</td>
<td>W5</td>
</tr>
<tr>
<td>S3a</td>
<td>N3a</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>N4</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>N5</td>
<td></td>
</tr>
<tr>
<td>S6</td>
<td>N6</td>
<td></td>
</tr>
<tr>
<td>S6a</td>
<td>N6a</td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td>N7</td>
<td></td>
</tr>
<tr>
<td>S7a</td>
<td>N7a</td>
<td></td>
</tr>
<tr>
<td>S7a</td>
<td>N7a</td>
<td></td>
</tr>
<tr>
<td>S8</td>
<td>N8</td>
<td></td>
</tr>
<tr>
<td>S9</td>
<td>N9</td>
<td></td>
</tr>
<tr>
<td>S10</td>
<td>N10</td>
<td></td>
</tr>
<tr>
<td>S10a</td>
<td>N10a</td>
<td></td>
</tr>
<tr>
<td>S10b</td>
<td>N10b</td>
<td></td>
</tr>
<tr>
<td>S11</td>
<td>N11</td>
<td></td>
</tr>
<tr>
<td>S12</td>
<td>N12</td>
<td></td>
</tr>
<tr>
<td>S13</td>
<td>N13</td>
<td></td>
</tr>
</tbody>
</table>

- **E1**: Wood and iron items
- **E1a**: Bike Parking
- **E2**: Storage of floor tiles
- **E2a**: Iron stands, clothes and nylon bags during the day
- **E3**: Storage of welding equipment
- **E3a**: Iron grille, jali, welding equipment and discarded rusted items
- **E4**: Bricks, metal items, burner, cooking pot
- **E5**: Welding equipment and metal work
- **E6**: Sewing Machine repair workshop
- **E6a**: Table of sewing machines requiring repair
- **E7**: Welding and metal work
- **E7a**: Welding equipment
- **E8**: Tea shop
- **E9**: Empty
- **E10**: Storage of bangles
- **E10a**: Bangle Shop
- **E10b**: Jewellery shop
- **N1**: Kitchen crockery shop
- **N1a**: Garment shop
- **N2**: Cloth shop
- **N2a**: Kitchen item shop
- **N3**: Key maker
- **N3a**: Garment shop
- **N4**: Ladies’ fashion shop (undergarments, hairclips etc.)
- **N4a**: Clothes stock
- **N5**: Cloth shop
- **N5a**: Ladies’ shoes
- **N6**: Cloth shop
- **N6a**: Shoe stock
- **N7**: Cloth shop
- **N7a**: Children’s garments
- **N8**: Cloth shop
- **N8a**: Ladies’ garments
- **N9**: Cloth shop
- **N9a**: Ladies’ garments
- **N10**: Storage
- **N10a**: Ready-made garments
- **N11**: Storage
- **N11a**: Ladies’ garments
- **N12**: Ladies’ shoe shop
- **N12a**: Burka Shop
- **N13**: haberdashery
- **N13a**: Ladies’ shoes
- **N14**: Shoe stock
- **N15**: Ladies’ shoes
- **N16**: Children’s garments
- **N17**: Storage of stock
- **N18**: Shoe storage
- **N19**: Ladies’ and children’s shoe shop
- **N20**: Handmade pots for kitchens
- **N21**: Ladies’ garments
- **N22**: Crockery shop
- **N23**: Ladies’ garments
- **N24**: Ladies’ garments
- **N25**: Ladies’ garments
- **N26**: Crockery shop
- **N27**: Ladies’ garments
- **N28**: Bakery / general store
- **N29**: Ladies’ garments

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USE OF SPACE AT LANYU" 189

Line marking the original right of way of Kotwali Bazaar

HOW OFTEN EACH SPACE IS ACCESSED:  
- Frequently accessed
- Sometimes accessed
- Never accessed
LEGEND FOR USE OF SPACE AT LEVEL 1

**MAIN PRAYER CHAMBER**
- **M1** Pedestal fan storage
- **M2** Quran stands and seating benches
- **M3** Book shelves
- **M4** Gas heater
- **M5** Speaker stand
- **M6** Mimbar
- **M7** Sound cabinet
- **M8** Quran stand

**NORTHERN ROW OF HUJRAS**
- **N1** Generator and electricity distribution room
- **N2** Imam and Hafeez’s sitting room
- **N3** Aqaf clerk
- **N4** Private room
- **N5** Electrician’s living room
- **N6** Mazan’s living room
- **N7** Aqaf library
- **N8** Rug storage and other bulky items
- **N9** Electrician’s room
- **N10** Room for shoe stand person
- **N11** Used by Aqaf
- **N12** Used by Archaeology Department
- **N13** Used by Archaeology Department

**SOUTHERN ROW OF HUJRAS**
- **S1** Electrical and miscellaneous items
- **S2** Rug storage
- **S3** Pedestal fans and new electrical items
- **S4** Shrine storage
- **S5** Storage Committee
- **S6** Storage Committee (unused)
- **S7** Aqaf storage and clerk’s room
- **S8** Water cooler
- **S9** Water cooler
- **S10** Rugs, charpai and dysfunctional water coolers
- **S11** Storage of ceramic items
- **S12** Water pump and geyser
- **S13** Archaeology Department storage
- **S14** Access to external latrines

**EASTERN SIDE OF COURTYARD**
- **E1** Storage Committee
- **E2** Electrical Items
- **E3** Storage of unused items
- **E4** Archaeology Department storage

**COURTYARD**
- **C1** Storage of prayer caps
- **C2** Plants for shrine

**CALLIGRAPHERS’ BAZAAR**
- **CB1** Keymaker and keymaker’s storage
- **CB2** Aqaf Office (junior staff)
- **CB3** Aqaf Office (Senior Manager)
- **CB4** Aqaf’s ‘Data Darbar’ medical dispensary
- **CB5** Aqaf’s ‘Data Darbar’ patient consulting room
- **CB6** Aqaf Department storage
- **CB7** Aqaf Department storage (documents and other records)
- **CB8** Aqaf Department storage (ceramic items)
- **CB9** Management Committee office
- **CB10** Plants
- **CB11** Shoe stand
- **CB12** Archaeology Department storage
- **CB13** Archaeology Department office
- **CB14** Archaeology Department storage
- **CB15** Storage Committee
- **CB16** Rubber handle workshop
- **CB17** Storage Committee
- **CB18** Archaeology Department storage
- **CB19** Archaeology Department storage
- **CB20** Empty
USE OF SPACE AT LEVEL 1
(See Legend Opposite)

HOW OFTEN EACH SPACE IS ACCESSED:
(foreign material is missing, area has been left blank)

- Frequently accessed (daily)
- Sometimes accessed (weekly or monthly)
- Rarely accessed (a few times per year)
- Never accessed
## LEGEND FOR USE OF SPACE IN WAZIR KHAN CHOWK

<table>
<thead>
<tr>
<th>NORTH SIDE</th>
<th>EAST SIDE</th>
<th>SOUTH SIDE</th>
<th>DIN NATH'S WELL</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1 Khalifa noon shop</td>
<td>E1 Closed shop</td>
<td>S1 Knife sharpener</td>
<td>DN1 Dupata and shawl shop</td>
</tr>
<tr>
<td>N2 Children's garment shop</td>
<td>E2 Shop</td>
<td>S2 Management of Syed Suf Shrine</td>
<td>DN2 Children's garments</td>
</tr>
<tr>
<td>N3 Boutique shop</td>
<td>E3 Tobacco shop</td>
<td>S3 Office</td>
<td>DN3 Children's garments</td>
</tr>
<tr>
<td>N4 Suitcase and bag shop</td>
<td>E4 Unknown</td>
<td>S4 Clothes Shop</td>
<td>DN4 Crockery shop</td>
</tr>
<tr>
<td>N5 Quilts, rugs, bedsheets etc</td>
<td>E5 Kozi Haleem shop</td>
<td>S5 Kabaria shop</td>
<td>DN5 Water and juice shop</td>
</tr>
<tr>
<td>N6 Children's garments</td>
<td>E6 Pakora shop (built in 1880)</td>
<td>S6 Cold drink supplier</td>
<td></td>
</tr>
<tr>
<td>N7 Mobile shop</td>
<td>E7 Artificial jewelery shop</td>
<td>S7 Electrician's workshop</td>
<td></td>
</tr>
<tr>
<td>N8 Cloth shop (with pathan style dresses)</td>
<td>E8 Children's garments</td>
<td>S8 Chicken tandoori shop</td>
<td></td>
</tr>
<tr>
<td>N9 Cosmetics and quilt shop</td>
<td>E9 Jewelery shop</td>
<td>S9 Food shop</td>
<td></td>
</tr>
<tr>
<td>N10 Tea shop</td>
<td>E10 Bag shop</td>
<td>S10 Metal workshop</td>
<td></td>
</tr>
<tr>
<td>N11 Small hotel specialising in lunches</td>
<td>E11 Knife Sharpener</td>
<td>S11 Metal workshop</td>
<td></td>
</tr>
<tr>
<td>N12 Tea shop</td>
<td>E12 Knife sharpener</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N13 Naan shop</td>
<td>E13 Knife sharpen</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ANGULAR PATHWAY**

- **AP1**: 11 shops specialising in clothes and shawls
- **AP2**: Handbag shop
- **AP3**: Tandoor oven
- **AP4**: Garbage collection point
- **AP5**: Begging area

**SYED SUF SHRINE**

- SS1: Parking for handcarts, rikshaws, bikes and cars
USE OF SPACE IN WAZIR KHAN CHOWK
(See Legend Opposite)

Patwari line established in February, 2010 marking the original right of way.
Interim Report
Structural Consolidation and Conservation of the Wazir Khan Mosque in Lahore.
This report sums up the results of the first three missions as structural consultant to the building complex and the conclusions from them up to now. It replies to section 1.1 – 1.4 of the contract of Dec. 2008/Jan. 2009: Preliminary evaluation, expert advice and specifications for tests, advice on monitoring, conceptual report on structural stability including recommendations for structural interventions.

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Soil ............................................................................................................................... 3
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Deformations ............................................................................................................. 4
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Thanks ....................................................................................................................... 6
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Appendices (10 pages)

The photographs were taken by myself during my visits to the site.

References


[4] Information, measurements, drawings by Aga Khan Cultural Services Pakistan, Lahore Team

Visits to the site
1 26 – 28 September 2008
2 14 – 19 April 2009

Initial situation
The brick masonry of the mosque shows cracks and deformations. The damage concentrates on the western part of the complex.

There are cracks in the walls, the parapet, and in the roof construction above the area for the prayers which consists of 5 cupolas and a flat slab around and between them. The cracks in the roof construction have been sealed from the top in former times. On the whole they remained tight up to now, indicating that a horizontal moving of the structure happened – a single one? – which came to rest since the last repair.

There are also cracks in the walls adjoining the minarets. The minarets subsided, the walls took over part of their weight. A process that came to rest as well.

The minarets themselves underwent a certain measure of tilting. At the present the structural stability of them proves to be sufficient.

For the future the main question remained whether new moving of the structure with new cracks in the walls and cupolas and tilting of the minarets are to be feared from the conditions of the soil. It was known that there is a thick layer of cultural deposit, but it was unknown in what depth the natural soil begins, how able it is to take loads, and how deep the foundations of the minarets reach down.

Investigation programme
An investigation programme was worked out to discover
- the conditions of the soil
- the measures of the minaret foundations
- the level of the bottom of the minaret foundations
- the extent of tilting of the minarets.
The programme was developed, the specifications were drawn up, and the realization was supervised with the help of Geotechnical Engineer Dr.-Ing. Michael Goldscheider, Karlsruhe. The programme was executed by the Soil Investigation Agency "Berkeley Associates", Lahore. The leaning of the minarets was measured by engineers of AKCS, Lahore.

Soil
Six exploratory boreholes were drilled down vertically to a depth of 25 m: four of them in the courtyard close to the four minarets, the fifth also in the courtyard near the western building unit, the sixth outside the courtyard in the SE corner of the Wazir Khan Square. Approximately, the results of the exploration resemble one another, they are meaningful not only for the mosque complex but also for the surrounding area of the Walled City.

The borings showed three layers: 4 – 8 m cultural fill in four of the six cases an intermediate layer of 2 – 3 m brown, stiff to very stiff, sandy clay / silty clay, and up to the maximum explored depth of 25 m grey, medium dense to dense silty sand / poorly graded sand.

As described further below, the bottom of the minaret foundations reaches down to firm soil: to sand and to stiff clay respectively. The consolidation of the clay is at its end, the related subsidence of the minarets came to rest; the bearing capacity of both sand and consolidated clay is high, there is no fear of new settlement movement.

The cultural fill of all investigated samples proved to be dampened. That may be the result of rainwater and, even more, of seepage from water mains or sewers. The dampness will not affect the natural soil below the minaret foundations, but penetration and retainer of water in the cultural fill may cause subsidence of parts of the courtyard and of walls which are not founded as deep as the minarets. In addition rising damp may occur in the walls. An example what can happen gives the drainage failure described in [2].

Minaret foundations
The geometry of the minaret foundations was determined from an excavated test pit right at the southern wall of the SE minaret. The depth of exploration by pit (3.97 m) and continuing auger holes (1.68 m) did not reach the bottom of the foundation. Steps of the wall profile lead to a probable width of the bottom of 9.05 m.

The bottom of the minaret foundations was explored by drilling a 10 m deep angle borehole through the foundation masonry of the SW minaret. The depth of the foundation came out to be 7.73 m below the floor level of the courtyard. The bottom level of the foundation block is situated, as mentioned above, in the firm soil, that is sand and sufficiently consolidated stiff clay. By this the stability of the minaret structure related to the soil conditions can be seen as guaranteed.

Strip foundations
There are a whole lot of buildings and foundations between the four minarets. Their walls don’t show severe cracks and subsidence. Their form and structure is diverse. A lot of test-pits and boreholes would have been necessary to achieve a complete overview of the build- ings foundations. The disturbance of the mosque area would have become too extensive. If during the restoration phase local problems occur, then restricted investigations are still possible.

Deformations
Plumbing of the four minarets was executed by the team of AKCS. The results were, besides the data of soil and foundations, needed for the calculation of the edge pressure underneath the minaret foundation, and for the decision whether preventive measures against further lifting of the minarets should be planned and carried out. In contrast to the visual impression, the leaning of the minarets proved to be minor. The centroidal distance of the different parts of the minaret from the plumb line of the crucial SW minaret is 0 cm (foundation) to 30 cm (cap). The distance of the total mass is 8.5 cm to the south, it influences the force distribution and stability rather slightly.

The cracks in the western building unit of the mosque complex show approximately a mirror image. That applies to the front wall, it’s parapet, the flat slab and the cupolas. It regards the position (appearing more in the North and South, less in the middle), the crack pattern in the flat slab and the adjoining parts of the cupolas, and the width of the cracks. The latter indicate that the NW and SW minaret moved aside and the structure between them was torn; front wall, parapet, slab and cupolas leaned, their lengthening corresponds to the sum of its cracks, and the sum of those cracks corresponds roughly to the remained leaning of the minarets. As already mentioned further above, the today’s situation looks like the result of a single occurrence. It seems a likely supposition that this was an earthquake. This assumption goes well with the gap between the SW part of the mosque and a neighbouring wall of another building, a gap which obviously occurred later as well.

Assessment of structural stability
Static loads: Based on the mentioned investigation data (soil, foundation, leaning of the minarets) and taking into consideration the static loads (dead weight, effect of inclination, wind) the minarets prove to be stable. The edge pressure of the consolidated soil (3.74 kpa/cm²) is low, the situation is safe.

Dynamic loads: The effect of dynamic loads, i.e., earthquake loads, has not been calculated. The today’s damage refers to the occurrence of an earthquake in the past. It caused cracks in the masonry, but no collapse. Lahore is not a place of high risk (Seismic zone 2 A). In case of a new earthquake the minarets may be shaken, but the explored situation of soil and foundation turned into certainty that they again will not collapse. New cracks in the masonry of the adjoining mosque buildings are not avoidable, they must be repaired anew. An earthquake calculation (which necessarily turns out to be relatively extensive) and it’s conclusions would not come to another result. And the “proof of time”, i.e., of more than 370 years, confirms it. Besides, Gilmore Hankey Kirk [3] come to a similar assessment.

Recommendations
The building complex and especially the minarets must not be underpinned. Extensive engineering reinforcement of the buildings is not advisable. Local structural measures should be planned and carried out by step in advance of the repair work of the craftsmen and restorers. Structural advice for local strengthening can be given case by case. To repair the monument and to fill up the cracks cautiously needs skilled craftsmanship and agreement with the consultant. The existing cementation [7] of the cracks in the flat slab and at the outer surface of the cupolas is to be examined, if necessary to be exchanged. The filling up of the cracks at the inner surface of the cupolas and in the parapet should be carried out in agreement with the restorer. It cannot be excluded that the repair of the cracks in the cupolas needs engineering measures. That depends on the until now inaccessible specific condition of the underside of the vaulted construction. If it consists of cement, the capping of the front wall in the west of the courtyard should be replaced by a construction of less expanding material.
Another recommendation is to extend the monitoring programme now and to measure and register the width of the accessible cracks periodically. That will help us later to select the most appropriate way and material for the repair.

Conclusions

The brick masonry of the Wazir Khan Mosque in Lahore shows cracks and deformations. The minarets underwent a certain measure of tilting. The question was whether new moving of the structure with new cracks and tilting are to be feared.

An investigation programme was worked out to discover the conditions of the soil, the dimensions of the minaret foundations, the level of their bottom, and the extent of the tilting.

Exploratory boreholes showed that the bottom of the minaret foundation reaches through a thick layer of cultural fill down to the natural soil. A test pit made steps visible which widen the minaret foundation. The cultural fill proved to be dampened, the natural soil to be consolidated.

Plumbing of the minarets turned out that the leaning of the minarets is minor than expected. The cracks in the building complex and the leaning of the minarets fit together. They point to effects of an earthquake.

By calculation the minaret proved to be safe against static loads. They can also be considered as resistant against the dynamic earthquake loads.

Engineering reinforcement can be restricted to local strengthening of weak areas. Most of the repair work can be done by skilled craftsmen. A close cooperation between them and the consulting engineer is advisable.

An extension of the monitoring programme to a periodical crack observation is recommendable.

Thanks
Thanks to the colleagues of AKCSP who supported my investigations to the best.

Fritz Wenzel 2009 November 25

List of Appendices 1a - 7b

1a, 1b Damage photos
2 Borehole Bh-03 (SW minaret)
3 Testpit photos (SE minaret)
4 Profile of minaret foundation (SE minaret)
5 Bottom level of minaret foundation (SW minaret)
6a, 6b Plumbing (NW and SW minaret)
7a, 7b Rough stability calculation
### Appendix B1

#### Appendix 3 - Testpit (SE minaret)

**Before**

**Cleared**

**Steps of the foundation wall**

**Auger hole**

---

**DESCRIPTION OF MATERIAL**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Material Description</th>
<th>BLOW COUNTS</th>
<th>STANDARD PENETRATION TEST PROFILE</th>
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<tr>
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<td>0.25</td>
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<td>Brown, very stiff</td>
<td>21</td>
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<td>2.00</td>
<td>Brown, medium dense,</td>
<td>21</td>
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<tr>
<td>2.25</td>
<td>Grey, medium dense,</td>
<td>25</td>
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<tr>
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<td>Trace with small pea</td>
<td>24</td>
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APPENDIX B1

Appendix Ga:
Leaning of the Northwest Minaret

Appendix Gb:
Leaning of the Southwest Minaret

WAZIR KHAN MOSQUE
Northwest Minaret-KOM Survey
Section 1 (looking West)

WAZIR KHAN MOSQUE
Southwest Minaret-KOM Survey
Section 1 (looking West)
Appendix B1: Rough Stability Calculations

Dead Load

Carpenters:
Assumptions: G_1 = 235600 kg, G_2 = 12000 kg
G_1 = 235600, G_2 = 12000

Geometrical distance from center line
of the moment: dx = 30 cm

Solid, square:
W = 500 x 500 x 10.00 = 2500 m^2
b = 250.0 x 250.0 = 625000 kg

Geometrical distance d = 7 cm

Solid, two-sided stepped:
W = b x 250.0 x 10.00 = 2500 m^2
b = 250.0 x 10.00 = 2500 kg

Geometrical distance d = 0 cm

Conclusion:
Southwest Market
Section: Positive West

Notes:
1) In accordance with appendix G_1
2) Specific gravity, local information.
3) Probably two-sided stepped, but for safety reasons not considered.

Wind

According to DIN 4085-4:

\[
H_1 = 1.62 \times 12.00 \times 2.70 = 1.5 \times 45 \times 4.5 = 434.0 \text{ kN}
\]

\[
H_2 = 0.80 \times 2.70 = 63.0 \times 4.5 = 274.5 \text{ kN}
\]

\[
H_3 = 0.80 \times 2.70 = 63.0 \times 4.5 = 274.5 \text{ kN}
\]

\[
\Sigma H = 2.85 \times 45 \text{ kN}
\]

Rough assumptions, on the safe side:

\[
W = 500 \times 90 \times 6 = 675000 \text{ kN}
\]

\[
\sigma_L = \frac{2.85 \times 45 \times 0.00006}{675000} = \frac{0.43 \text{ kN/m}^2}{6}
\]

Learning:

\[
\Sigma H_L = 417 \times 10^{-3} + 235 \times 0.20 + 225000 \times 0.09 = 413.2 \text{ kN}
\]

\[
W = 475000 \text{ kN/m}^2
\]

\[
\sigma_L = 149 \times 45 \times 675000 = 0.10 \text{ kN/m}^2
\]

\[
\sigma' = \frac{4.49 \times 45 \times 675000 \pm 0.03 \times 45 \times 0.10}{500 \times 900} = 3.13 \pm 0.18
\]

\[
\sigma = \frac{3.13 \times 45}{500 \times 900} = \frac{3.73 \times 45}{500 \times 900} \leq \sigma' \text{ allowable}
\]

Altogether

25.01.2009: Fritz Wunder
REPORT ON THE FOURTH FIELD MISSION TO WAZIR KHAN MOSQUE LAHORE
5-7 JUNE 2010

Initial position

Starting point for this paper is my Interim Report "Structural Consolidation and Conservation of the Wazir Khan Mosque in Lahore" from 25 November 2009. After investigation of masonry damage, conditions of soil, minaret foundation, and extent of minaret tilting, the Interim Report reached those conclusions. Structure, foundation, and subsoil of the mosque are safe enough against further loads and deformations. Engineering reinforcement can be restricted to local strengthening of weak areas. Most of the repair work can be done by skilled craftsmen. Occasional structural advice will be sufficient.

This time the following themes were on the agenda of the visit, and appropriate kinds of action were discussed and considered:

Crack pattern in general

In the main the masonry of the mosque shows elder cracks. This fact doesn't exclude that part of them got widened in recent time. The reasons for cracking are different:

Firstly the higher own weight of the minarets and because of that their higher settlement in comparison with the adjacent walls, whose adjoining parts act now as unintended buttresses of the minarets and cracked accordingly.

Secondly, probably as a result of earthquake: A certain tilting of the minarets influenced the fabric of the Prayer Chamber in the West and led to cracks in the parapet and the vaults behind.

Thirdly, gaps and cracks in the South of the mosque complex and in the neighbouring houses are dealt with further below.

Fourthly: Apart from the structurally relevant cracks the building shows a number of narrow fissures and chinks, what is usual for such expanded masonry complexes.

Levelling of the roof edge around the courtyard

In accordance with an idea of Masood Khan, my proposal is to carry out a levelling of the roof edge around the courtyard. The measured divergences from the horizontal will lead to a more differentiated understanding of the particular crack pattern and the reasons for it. Please send the results of the levelling to Karlsruhe in due course.

Crack treatment in general

For the repair of the structurally not relevant fissures and chinks, traditional methods, techniques, and materials should be applied. Please use lime-mortar, no cement- or resin-based mortar!
For the filling of the structural relevant cracks with mortar, proven grouting methods and techniques do exist. Pure cement-mortar is to be avoided, the admixture of cement to the lime-mortar is to be restricted to the (for hardening) necessary minimum.

Stitching, i.e. inserting of steel bars across a masonry crack, proves to be ineffective, because in case of new tension- or shear forces the masonry will fail next to the old crack.

To repair a cracked area not by injection but by removing old bricks and inserting new ones is (only then and there) recommendable, where the crack is very wide, or the masonry beside the crack shows damage itself.

Cracking and tilting of vault and wall of the Middle Pavilion South

The thrust of the barrel vault pushed the upper part of the southern wall outwards and caused a wide gap in the crown of the vault. The gap runs through from the eastern to the western end of the vault (Fig. 1 and 2). The shift of the southern wall is visible at the eastern wall up in the corner (Fig. 3). The condition of the outer corner including bond and joints of both walls is insufficient as well (Fig. 4).

My idea for an unobtrusive repair is to insert 3 or 4 tie rods, crossing the room right under the vault, and to close the long and wide gap by bricks and mortar. On the basis of a survey and record drawings of the structure, I could work out a corresponding structural proposal. The outside corner needs repair by craftsmen.

Gap between Mosque and adjacent house in the South

The gap between the mosque and the adjacent house in the South (Fig. 5) is similar to the gap further away in the South-West (Fig. 6), described in my Interim Report of 25 November 2009. Recommendation: Don’t fill up the gaps with grout, leave them open, avoid seeping of rain water into them by closing their edges with compressible material.

Cracks in the neighbouring property in the South

The neighbouring property in the South shows cracks in the wall adjoining the mosque (Fig. 7). An investigation of the inner structure and damage condition of the building is recommended, negative influence of a weak structure on the construction of the mosque should be assessable in good time.

Discussion with the archaeologist

In a discussion and a round of the building complex (Fig. 8) questions arose about the origin of the rising damp in the area. There was an agreement that the main reason is to be seen in the leaky trade water mains and sewers.

I was asked for a settlement prognosis for the soil of the mosque area. My answer was that no further subsidence is to be feared from the natural soil, which follows 4-8 m below the cultural fill and proved to be the base for the minaret foundations.

Different from this is the situation of the cultural fill. Its further behaviour depends on the change of dampness and is not predictable. I can only repeat what I wrote on this problem in my Interim Report in November 2009:

„The cultural fill of all investigated samples proved to be dampened. That may be the result of rainwater and, even more, of seepage from water mains and sewers. The dampness will not affect the natural soil below the minaret foundations, but penetration and retaining of water in the cultural fill may cause subsidence of parts of the courtyard and of walls which are not founded as deep as the minarets. In addition, rising damp may occur in the walls.“

Thanks

Thanks again to the colleagues of AKCSP who supported my site mission to the best.

Fritz Wenzel 12 July 2010

Below 8 photos, taken by myself
Fig. 1, 2 Gap in the crown of the southern barrel vault of Middle Pavilion South

Fig. 3 Shift of the southern wall by thrust of the barrel vault (see upper corner)

Fig. 4 Condition of the outer corner between southern and eastern wall

Fig. 5 Gap between mosque and adjacent house in the South

Fig. 6 Similar gap further away in the South-West area of the mosque

Fig. 7 Crack in the wall of the neighbouring property in the South

Fig. 8 Round with the archaeologists
Conservation, Rehabilitation and Sustainable Development of Walled City Lahore
(Geotechnical Investigations for Wazir Khan’s Mosque)

Factual Report on Geotechnical Investigations

October 10, 2009

Aga Khan Cultural Services, Pakistan

Soil Investigation Agency

Berkeley Associates

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FACTUAL REPORT ON GEOTECHNICAL INVESTIGATIONS

Document No. J-488

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Fig. 2-2 Profile of Observed SPT N-values  
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1 INTRODUCTION

1.1 General

Aga Khan Cultural Services, Pakistan in collaboration with Government of Punjab has initiated the project of “Conservation, Rehabilitation and Sustainable Development of Walled City Lahore”. As a part of this project, geotechnical investigations had been planned in order to start the studies leading to the conservation of Wazir Khan Mosque. M/s Berkeley Associates have been entrusted with execution of Geotechnical Investigations for the Wazir Khan Mosque. The scope of work for the geotechnical investigations was prepared by Project Consultant M/s Buro fur Baukonstruktionen GmbH, Karlsruhe Germany.

The geotechnical investigations comprised drilling of boreholes, performance of in-situ tests in the boreholes and collection of soil from the boreholes and performance of laboratory testing on selected soil samples as per laboratory testing advice prepared by Project Consultant.

The field work for these geotechnical investigations was carried out during the period from August 10, 2009 to October 05, 2009.

1.2 Scope of Work

The scope of geotechnical investigations is as follows;

- Drilling of seven (07) exploratory boreholes (six (06) vertical and one (01) inclined)
- Excavation of testpit
- Performance of standard penetration tests (SPTs) in the boreholes.
- Collection of disturbed and undisturbed samples.
- Obtaining pertinent ground water information in the boreholes.
- Performance of laboratory tests on selected soil samples.
- Preparation of a factual geotechnical investigation report upon completion of field and laboratory testing.

1.3 Methodology

Keeping in view the scope of work and specifications generally followed for the geotechnical studies, a programme of field work was prepared. The exploratory borings were drilled using both hand auger cum light percussion drilling method in cultural fill and straight rotary drilling method in natural soil.

Angle bore hole was drilled at an angle of 15 degrees with vertical using straight rotary drilling rig and steel casing. The samples were recovered through single tube core barrel.

The excavation of testpit was made manually in 1 V: 0.23 H configuration.

Standard penetration tests (SPTs) were performed in designated boreholes in natural soil in accordance with ASTM D 1586.

The cultural fill samples were collected, rapped in polythene bags and preserved in wooden boxes. These samples were preserved without wasting even a single sample in order to get a continuous formation.

Soil samples were also collected from natural soil using appropriate samplers for identification and subsequent laboratory testing. Selected soil samples were subjected to various laboratory tests for evaluation of classification, strength and chemical characteristics of sub-soils.

This report has been prepared on the basis of geotechnical investigations carried out at the project site and subsequent laboratory testing performed on the selected soil samples.
2 FIELD INVESTIGATIONS

2.1 General

Keeping in view the scope of the geotechnical studies, the field investigation programme was prepared. These field investigations included the following activities:

- Drilling of exploratory boreholes
- In-situ testing in the boreholes
- Soil sampling from boreholes

Photographs taken at site during the field investigations are attached in Appendix-D.

The details of the field work are discussed in this chapter.

2.2 Exploratory Boreholes

A total of seven (07) boreholes were drilled at site. The locations of these boreholes are shown in Fig. 2-1.

BH-1 to BH-6 were drilled vertically each down to a depth of 25 m below the finished floor level (FFL) whereas; BH-7 was drilled through the minaret foundation at an angle of 15 degrees with vertical. This angle borehole was drilled up to 2.0 m below the bottom of foundation of minaret which hit at a depth of 8.0 m below the finished floor level (FFL). For continuous sampling of cultural fill, all the boreholes except BH-7 were drilled using hand auger cum light percussion drilling method and thereafter drilled by straight rotary drilling method in natural soil. The detail of drilling is given in the following table:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Borehole Designation</th>
<th>Depth drilled in Cultural Fill (m)</th>
<th>Depth drilled in Natural Soil (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BH-1</td>
<td>5.0</td>
<td>20.0</td>
</tr>
<tr>
<td>2</td>
<td>BH-2</td>
<td>4.0</td>
<td>21.0</td>
</tr>
<tr>
<td>3</td>
<td>BH-3</td>
<td>5.0</td>
<td>20.0</td>
</tr>
<tr>
<td>4</td>
<td>BH-4</td>
<td>6.0</td>
<td>19.0</td>
</tr>
<tr>
<td>5</td>
<td>BH-5</td>
<td>8.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

The diameter of all the boreholes was 100 mm. SPTs were performed in these boreholes at 1.0 depth interval in natural soil. Disturbed and Undisturbed soil samples were collected from the boreholes using appropriate samplers. Brick samples of foundation were also collected from angle borehole since cores were not possible due to zero RQD.

A careful record of all the materials encountered in each borehole was maintained in the form of borehole logs. Data of SPTs conducted in each hole was also recorded on the respective borehole logs. The borehole logs are included in Appendix-B.

2.3 Testpit Excavation

To obtain the details of minaret foundation and visual classification of foundation soils at shallow depth, one (01) testpit was manually excavated down to a depth of 3.97 m below the finished floor level (FFL). Subsurface log of the testpit was prepared after carefully observing the soils on the walls of the excavated pit. Location of testpit is shown on Fig. 2-1. The testpit log is also included in Appendix-B.

Three (03) additional auger holes were drilled at the bottom of testpit in order to access the further foundation details. These auger holes were drilled down to 1.38 m from bottom of testpit.

2.4 In-situ Testing in Boreholes

During the field investigations, standard penetration tests (SPTs) were carried out in all the boreholes except BH-7. A brief description of the test is provided in the following section.

2.4.1 Standard Penetration Tests

For evaluating the consistency and compactness of the foundation soils, the standard penetration tests (SPTs) were performed in all the designated exploratory boreholes except BH-7 in natural soil. SPTs were conducted in accordance with the procedures described in latest version of ASTM designation D 1586. A donut type hammer, weighing 63.5 kg, has been used for the tests. The hammer was lifted and dropped mechanically through a manila rope using pulley hanged to a tripod. Prior to performing each SPT, the loose material existing in the hole was properly removed. A split spoon sampler without a liner was used for all the tests. Disturbed soil samples were collected from the boreholes at 1.0 depth interval in natural soil.
2.5 Sampling in Boreholes

The cultural fill samples were collected, rapped in polythene bags and preserved in wooden boxes. These samples were preserved without wasting even a single sample in order to get a continuous formation.

Disturbed and undisturbed soil samples were also obtained from natural soil during these soil investigations. Disturbed soil samples were obtained from the boreholes through split spoon sampler while performing SPTs. The disturbed samples were placed in polythene bags and preserved in wide-mouthed plastic jars. The jars were clearly labelled to indicate the project name, project code, borehole designation and depth of sample. Undisturbed soil samples from cohesive soils were obtained from the boreholes by appropriate sampler. The Shelby tubes containing undisturbed soil samples were properly waxed and labelled to indicate the project name, project code, borehole designation and depth of sample. Brick samples of foundation were also recovered from angle borehole. These samples were preserved in wooden box. All the soil samples were carefully transported to our testing laboratory.

2.6 Groundwater Observations

At the time of these investigations, ground water table was not encountered in any of the borehole drilled down to a maximum depth of 25 m. However, some trapped water in the cultural fill was encountered.

3 LABORATORY TESTING

For evaluation of physical and mechanical characteristics of the sub-soils, selected disturbed and undisturbed soil samples were tested in the laboratory. The laboratory testing was carried out at testing facilities of Berkeley Associates Lahore. The laboratory testing program was prepared by the project Consultant. The following laboratory tests were performed on selected soil samples.

- Particle size distribution
- Atterberg’s limits
- Bulk density
- In-situ moisture content

A brief description of these tests is given in the following sections. A summary of laboratory test results is provided in Table 3-1.

3.1 Particle Size Distribution

For classifying the subsurface soils, eleven (11) selected soil samples were subjected to sieve analyses during these studies. Most of the samples containing more than 30 percent material passing sieve no. 200 were further subjected to hydrometer analyses. The sieve analyses were performed in accordance with the procedures specified in ASTM designation D 422, with sample preparation by ASTM designation D 2217 (wet preparation method), Procedure B. The hydrometer analyses were carried out in accordance with procedure as specified in ASTM designation D 422. Results of sieve and hydrometer analyses were plotted in the form of gradation curves. These curves for all the tested samples are presented in Appendix-C. The percentages of fines (passing sieve no. 200), sand and concretion fractions of the tested soil samples are also indicated in Table 3-1.

3.2 Atterberg Limits

For evaluating plasticity characteristics of cohesive soils, liquid and plastic limit tests were performed on two (02) selected soil samples. The tests were performed as specified in ASTM designation D 4318. Both the liquid limit tests were performed with at least three trials. The test results are summarized in Table 3-1. According to Casagrande’s Plasticity Chart (shown as Fig. 3-1), the fine-grained soil samples are classified as CL.
3.3 Bulk and Dry Density

Three (03) undisturbed soil samples were tested for determination of their bulk densities. The test results are provided in Table 3-1. The bulk density of the tested samples ranges from 15.8 kN/m³ to 18.1 kN/m³.

3.4 In-situ Moisture Content

Six (06) undisturbed soil samples were tested for determination of their in-situ moisture contents. The test results are provided in Table 3-1. The in-situ moisture content of the tested samples ranges from 17.0 % to 26.9 %.

4 GEOTECHNICAL CHARACTERIZATION OF SUBSOIL

4.1 General

The geotechnical investigations carried out for the project comprised field and laboratory work. The field and laboratory investigations were aimed at evaluating the physical characteristics of the foundation soils. The subsurface conditions and physical characteristics of the soils existing at the project site are discussed in the following sections.

4.2 Geology

The natural soil deposits at the project site belong to Chung Fun formation. These alluvial deposits comprise earthy brown to brown silt, clay and sand. The beds are largely hard, laminated and sandy with interbeds of clay and layers or lenses of sand. The cultural fill is underlain by natural soil deposit.

4.3 Seismicity

According to Building Code of Pakistan (Seismic Provisions – 2007), issued by Government of Islamic Republic of Pakistan, Seismic Zone 2A has been assigned to Lahore. Peak ground acceleration associated with Zone 2A has been recommended to vary from 0.08g to 0.16g.

4.4 Stratigraphy

During these investigations, the subsurface was explored to a maximum depth of twenty five (25) m below the existing ground surface and the following geotechnical units have been identified:

<table>
<thead>
<tr>
<th>Soil Unit</th>
<th>Description</th>
<th>Layer Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>Cultural fill</td>
<td>4.0 m - 8.0 m</td>
</tr>
<tr>
<td>Layer 2</td>
<td>Brown stiff to very stiff lean clay/ silty clay</td>
<td>2.0 m - 3.0 m</td>
</tr>
</tbody>
</table>
5 EXISTING FOUNDATIONS

Different methodologies were adopted to determine the geometry and depth of existing foundation of minaret; and are as follows:

- Excavation of testpit
- Drilling of angle borehole

The details of these methodologies are discussed in the following sections.

5.1 Excavation of Testpit

To determine the geometry of foundation, one (01) testpit was excavated near Minaret. The test pit was excavated manually having the plan dimensions of 4'-6" X 5'-0". Depth of the testpit was limited to 3.97 m below natural ground level due to the stability problems. Beyond this depth, three (03) auger holes were also drilled at the bottom of testpit to determine the remaining features of the footing. However, the actual depth of foundation could not be reached and determined. Foundation profile obtained from excavation of the testpit and drilling of auger holes is shown on Fig. 5-1.

5.2 Drilling of Angle Borehole

In order to determine the actual depth of existing foundation, a supplementary 10 m deep angle borehole was drilled near Minaret. The borehole was drilled inside courtyard at an angle of 15 degrees with the vertical by using straight rotary drilling method.

After drilling the angle borehole, the depth of foundation came out to be 7.73 m below the finished floor level (FFL) of courtyard and is shown in Fig. 5-2.
6 CONCLUSIONS

1. During these investigations, the subsurface was explored to a maximum depth of twenty five (25) m below the existing ground surface. The location of boreholes and testpit is shown on Fig. 2-1. Various soil layers encountered at the site below the existing ground surface are described in section 4.4 and graphically represented in linear subsurface profile shown on Figs. 4-1 & 4-2.

2. After the excavation of testpit, drilling of auger holes at the bottom of testpit and drilling of angle borehole near the minaret, the interpreted width of foundation came out to be 9.05 m whereas depth of foundation came out to be 7.73 m below finished floor level (FFL) of mosque courtyard. The details of existing minaret foundation are shown on Fig. 5-2.

3. At the time of these investigations the ground water table was not encountered in any of the borehole except some trapped water or soil in saturated state in top cultural fill.

4. On the basis of our evaluations, the soil profile type as per Pakistan Building Code should be taken as S\(_p\) (i.e. Stiff Soil).
### Table 3-1 Summary of Laboratory Test Results

<table>
<thead>
<tr>
<th>Borehole No.</th>
<th>Sample No.</th>
<th>Depth (m)</th>
<th>Particle Size Analysis</th>
<th>Atterberg Limits</th>
<th>Bulk Density</th>
<th>N.M.C %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conc.</td>
<td>Sand</td>
<td>Fines</td>
<td>LL</td>
</tr>
<tr>
<td>BH 02</td>
<td>UDS-2</td>
<td>7.5</td>
<td>5.1</td>
<td>3.9</td>
<td>91.0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>SPT-6</td>
<td>10.0</td>
<td>0.0</td>
<td>42.8</td>
<td>57.2</td>
<td>12.1</td>
</tr>
<tr>
<td>BH 03</td>
<td>UDS-1</td>
<td>7.5</td>
<td>0.0</td>
<td>2.7</td>
<td>97.3</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>SPT-7</td>
<td>11.0</td>
<td>0.0</td>
<td>71.8</td>
<td>28.1</td>
<td>18.1</td>
</tr>
<tr>
<td>BH 04</td>
<td>SPT-3</td>
<td>7.0</td>
<td>0.0</td>
<td>1.0</td>
<td>98.0</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td>SPT-6</td>
<td>10.0</td>
<td>0.0</td>
<td>82.5</td>
<td>17.5</td>
<td></td>
</tr>
<tr>
<td>BH 05</td>
<td>UDS-1</td>
<td>8.0</td>
<td>0.0</td>
<td>49.7</td>
<td>50.3</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td>SPT-2</td>
<td>10.0</td>
<td>0.0</td>
<td>68.1</td>
<td>31.9</td>
<td></td>
</tr>
<tr>
<td>BH 06</td>
<td>SPT-4</td>
<td>7.0</td>
<td>0.0</td>
<td>22.0</td>
<td>78.0</td>
<td>20.8</td>
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<tr>
<td></td>
<td>SPT-7</td>
<td>10.0</td>
<td>0.0</td>
<td>89.9</td>
<td>10.1</td>
<td></td>
</tr>
</tbody>
</table>

Tested by: Asif Imran  
Checked by: Muhammad Ajmal  
Approved by: Engr. Farooq Naveed
APPENDIX C

Fig. 3-1 Casagrande Plasticity Chart

Fig. 3-2 Profile of Observed SPT N Values Versus Depth
APPENDIX - B

BORE HOLE & TESTPIT LOGS

<table>
<thead>
<tr>
<th>DEPTH (m)</th>
<th>SPT</th>
<th>DESCRIPTION OF MATERIAL</th>
<th>BOREHOLE NO.</th>
<th>DEPTH OF W.T. (m)</th>
<th>FINAL DEPTH (m)</th>
<th>SPT BLOWS FOR LAST 30 cm PENETRATION</th>
<th>STANDARD PENETRATION TEST PROFILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>FILL MATERIAL</td>
<td>B-15</td>
<td>0</td>
<td>0.00</td>
<td>6</td>
<td>100%</td>
</tr>
<tr>
<td>0.5</td>
<td>SPT-1</td>
<td>0.5 to 0.75 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>SPT-2</td>
<td>0.5 to 1 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SPT-3</td>
<td>1.5 to 2 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SPT-4</td>
<td>2.5 to 3 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SPT-5</td>
<td>3.5 to 4 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SPT-6</td>
<td>4.5 to 5.5 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SPT-7</td>
<td>5.5 to 6.5 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SPT-8</td>
<td>6.5 to 7.5 m black sand</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
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<thead>
<tr>
<th>DEPTH (m)</th>
<th>DESCRIPTION OF MATERIAL</th>
<th>SPT BLOWS FOR LAST 30 cm PENETRATION</th>
</tr>
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<tbody>
<tr>
<td>20</td>
<td>Grey, medium dense</td>
<td>74.5 SPT-15</td>
</tr>
<tr>
<td>21</td>
<td>SILTY SAND</td>
<td>73.5 SPT-18</td>
</tr>
<tr>
<td>22</td>
<td>trace mica.</td>
<td>72.5 SPT-17</td>
</tr>
<tr>
<td>23</td>
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<td>71.5 SPT-18</td>
</tr>
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<td>24</td>
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<td>70.5 SPT-19</td>
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<td>25</td>
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<td>89.5 SPT-20</td>
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<td>26</td>
<td>(BOTTOM OF BOREHOLE)</td>
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CLIENT: Aga Khan Culture Services, Pakistan
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Reduced Level</th>
<th>Description of Material</th>
<th>SPT Bows for Last 30 cm Penetration</th>
<th>Standard Penetration Test Profile</th>
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<tbody>
<tr>
<td>0 - 20</td>
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<td>25</td>
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Hydraulic Bored Straight Rotary Cutting

(BOTTOM OF BOREHOLE)

CLIENT:
Aga Khan Culture Services, Pakistan
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<thead>
<tr>
<th>Depth (m)</th>
<th>SPT</th>
<th>Description</th>
<th>Standard Penetration Test Profile</th>
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<td></td>
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<tr>
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<td>SPT-16</td>
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<tr>
<td>0.3</td>
<td></td>
<td>SILTY SAND, trace mica.</td>
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</tr>
<tr>
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<td></td>
<td></td>
</tr>
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<td></td>
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<th>Legend</th>
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<th>SPT BLOWS for LAST 30 cm PENETRATION</th>
<th>STANDARD PENETRATION TEST PROFILE</th>
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<td>22</td>
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<tr>
<td>25</td>
<td>19.5</td>
<td>SPT-17</td>
<td>(BOTTOM OF BOREHOLE)</td>
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<td>18.7</td>
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<td>18.6</td>
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<td>18.3</td>
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<tr>
<td>38</td>
<td>18.2</td>
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<td></td>
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</tr>
<tr>
<td>39</td>
<td>18.1</td>
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</table>

CLIENT: Aga Khan Culture Services, Pakistan
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description of Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Red Brown, layer by layer</td>
</tr>
<tr>
<td>1</td>
<td>Bricks mixed with mixture of limestone</td>
</tr>
<tr>
<td>2</td>
<td>Brick, soil mixed with pieces of brick</td>
</tr>
<tr>
<td>3</td>
<td>Brown, moist to saturated</td>
</tr>
<tr>
<td>4</td>
<td>Mixed with pieces of bricks</td>
</tr>
<tr>
<td>5</td>
<td>Brown, saturated soil (C near 50%)</td>
</tr>
<tr>
<td>6</td>
<td>Mixed with pieces of brick</td>
</tr>
</tbody>
</table>

(BOTTOM OF TEST PIT)

LABORATORY TEST RESULTS
Grain Size Analysis

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Passing %</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.8 mm</td>
<td>100.0</td>
</tr>
<tr>
<td>38.1 mm</td>
<td>100.0</td>
</tr>
<tr>
<td>25.4 mm</td>
<td>100.0</td>
</tr>
<tr>
<td>19.00 mm</td>
<td>100.0</td>
</tr>
<tr>
<td>12.7 mm</td>
<td>100.0</td>
</tr>
<tr>
<td>9.51 mm</td>
<td>100.0</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>94.9</td>
</tr>
<tr>
<td>2.00 mm</td>
<td>93.8</td>
</tr>
<tr>
<td>1.9 mm</td>
<td>93.6</td>
</tr>
<tr>
<td>0.425 mm</td>
<td>93.3</td>
</tr>
<tr>
<td>0.297 mm</td>
<td>93.1</td>
</tr>
<tr>
<td>0.149 mm</td>
<td>91.9</td>
</tr>
<tr>
<td>0.075 mm</td>
<td>91.0</td>
</tr>
</tbody>
</table>

Client: Aga Khan Cultural Services, Pakistan

Sample No: UDS-2

Sample Type: Undisturbed

Approved by: Engr. Farooq Naveed

Tested by: Asif Imran

Checked by: Muhammad Ajmal
Grain Size Analysis

Project: Conservation, Rehabilitation and Sustainable Development of Walled City Lahore
(Geotechnical Investigations for Wazir Khan's Mosque)

Client: Aga Khan Cultural Services, Pakistan

Lab Ref.: J 488/L-018/09

Date: 28/09/2009

Sample No.: SPT-6

Sample Type: Disturbed

Tested by: Asif Imran
Checked by: Muhammad Ajmal
Approved by: Engr. Farooq Naveed

BH-2

Depth: 10.0 meter

Sample Type: Disturbed

Seive Size (mm)

<table>
<thead>
<tr>
<th>Passing % age</th>
</tr>
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<tbody>
<tr>
<td>50.8 100.0</td>
</tr>
<tr>
<td>38.1 100.0</td>
</tr>
<tr>
<td>25.4 100.0</td>
</tr>
<tr>
<td>19.00 100.0</td>
</tr>
<tr>
<td>12.7 100.0</td>
</tr>
<tr>
<td>9.51 100.0</td>
</tr>
<tr>
<td>4.75 100.0</td>
</tr>
<tr>
<td>2.00 99.7</td>
</tr>
<tr>
<td>1.19 99.1</td>
</tr>
<tr>
<td>0.425 98.3</td>
</tr>
<tr>
<td>0.297 98.0</td>
</tr>
<tr>
<td>0.149 77.8</td>
</tr>
<tr>
<td>0.075 57.3</td>
</tr>
</tbody>
</table>

Average Grain Diameter (mm)

Percentage Passing (%)

0.005 mm

0.0

0.001

0.001

0.01

0.1

1

10

100

300 mm

0.05 mm

0.1 mm

0.75 mm

30 mm

75 mm
# Grain Size Analysis

**Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

**Client:** Aga Khan Cultural Services, Pakistan  
**Lab Ref.:** J 488/L-018/09  
**Date:** 28/09/2009  
**Sample No.:** SPT-8  
**Sample Type:** Disturbed  
**BH-2 Depth:** 12.0 meter

<table>
<thead>
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<th>Passing %</th>
<th>Percentage Passing (%)</th>
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</thead>
<tbody>
<tr>
<td>50.8</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>38.1</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>25.4</td>
<td>100.0</td>
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<tr>
<td>19.00</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>12.7</td>
<td>100.0</td>
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<td>9.51</td>
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<td>4.75</td>
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<td>2.00</td>
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<tr>
<td>1.19</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>0.425</td>
<td>99.8</td>
<td></td>
</tr>
<tr>
<td>0.297</td>
<td>99.5</td>
<td></td>
</tr>
<tr>
<td>0.149</td>
<td>34.1</td>
<td></td>
</tr>
<tr>
<td>0.075</td>
<td>13.8</td>
<td></td>
</tr>
</tbody>
</table>

**Tested by:** Asif Imran  
**Checked by:** Muhammad Ajmal  
**Approved by:** Engr. Farooq Naveed
# Grain Size Analysis

**Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

**Client:** Aga Khan Cultural Services, Pakistan  |  **Lab Ref.:** J 488/L-018/09  |  **Date:** 28/09/2009

**BH-3**  
**Depth:** 7.5 meter  |  **Sample No.:** UDS-1  |  **Sample Type:** Undisturbed

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Percentage Passing (%)</th>
</tr>
</thead>
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<td>300</td>
<td>100.0</td>
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<td>150</td>
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<td>75</td>
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<td>5</td>
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<td>2.0</td>
<td>99.5</td>
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<td>1.19</td>
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<td>0.425</td>
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<td>98.6</td>
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<tr>
<td>0.149</td>
<td>98.0</td>
</tr>
<tr>
<td>0.075</td>
<td>97.3</td>
</tr>
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</table>

**Average Grain Diameter (mm)**

<table>
<thead>
<tr>
<th>Grain Size</th>
<th>Percentage Passing (%)</th>
</tr>
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<tbody>
<tr>
<td>75</td>
<td>100.0</td>
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<tr>
<td>30</td>
<td>100.0</td>
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<tr>
<td>15</td>
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<td>10</td>
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<tr>
<td>5</td>
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<td>2.0</td>
<td>99.5</td>
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<td>1.19</td>
<td>99.3</td>
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<tr>
<td>0.425</td>
<td>98.7</td>
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<td>98.6</td>
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<tr>
<td>0.149</td>
<td>98.0</td>
</tr>
<tr>
<td>0.075</td>
<td>97.3</td>
</tr>
</tbody>
</table>

**Sample Type:** Undisturbed

**BH-3 Depth:** 7.5 meter

**Client:** Aga Khan Cultural Services, Pakistan

**Approved by:** Engr. Farooq Naveed

**Tested by:** Asif Imran  |  **Checked by:** Muhammad Ajmal

---

**Notes:**

- The grain size analysis was conducted using sieving methods.
- The sample was collected at a depth of 7.5 meters from the ground surface.
- The sample was classified as undisturbed soil.
- The soil consists of various grain sizes ranging from silt to cobbles.
- The soil texture analysis indicates a predominance of fine to medium sand, with some silt and clay content.

---

**Additional Information:**

- The project aims to conserve, rehabilitate, and sustain the Walled City of Lahore, focusing on the geotechnical aspects.
- The investigation was carried out for the restoration of Wazir Khan's Mosque.
### Grain Size Analysis

**Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

**Client:** Aga Khan Cultural Services, Pakistan

**Lab Ref.:** J 488/L-018/09

**Date:** 28/09/2009

**BH-3**

- **Depth:** 11.0 meter
- **Sample No.:** SPT-7
- **Sample Type:** Disturbed

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Passing %</th>
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<tbody>
<tr>
<td>50.8</td>
<td>100.0</td>
</tr>
<tr>
<td>38.1</td>
<td>100.0</td>
</tr>
<tr>
<td>25.4</td>
<td>100.0</td>
</tr>
<tr>
<td>19.00</td>
<td>100.0</td>
</tr>
<tr>
<td>12.7</td>
<td>100.0</td>
</tr>
<tr>
<td>9.51</td>
<td>100.0</td>
</tr>
<tr>
<td>4.75</td>
<td>100.0</td>
</tr>
<tr>
<td>2.00</td>
<td>100.0</td>
</tr>
<tr>
<td>1.19</td>
<td>100.0</td>
</tr>
<tr>
<td>0.425</td>
<td>99.9</td>
</tr>
<tr>
<td>0.297</td>
<td>99.2</td>
</tr>
<tr>
<td>0.149</td>
<td>71.5</td>
</tr>
<tr>
<td>0.075</td>
<td>28.1</td>
</tr>
</tbody>
</table>

**Average Grain Diameter (mm):**

- **Boulder**
- **Cobbles**
- **Gravel**
- **Sand**
  - Coarse
  - Medium
  - Fine
- **Silt**
- **Clay**

**Approved by:** Engr. Farooq Naveed

**Tested by:** Asif Imran

**Checked by:** Muhammad Ajmal
Grain Size Analysis

Project: Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

Client: Aga Khan Cultural Services, Pakistan
Lab Ref.: J 488/L-018/09
Date: 28/09/2009

BH-4
Depth: 7.0 meter
Sample No: SPT-3
Sample Type: Disturbed

Seive Size (mm) | Passing %
---|---
50.8 | 100.0
38.1 | 100.0
25.4 | 100.0
19.00 | 100.0
12.7 | 100.0
9.51 | 100.0
4.75 | 100.0
2.00 | 99.8
1.19 | 99.7
0.425 | 99.6
0.297 | 99.6
0.149 | 99.4
0.075 | 99.0

Tested by: Asif Imran
Checked by: Muhammad Ajmal
Approved by: Engr. Farooq Naveed
Grain Size Analysis

Project: Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

Client: Aga Khan Cultural Services, Pakistan

Lab Ref.: J 488/L-018/09

Date: 28/09/2009

BH-4

Depth: 10.0 meter

Sample No: SPT-6

Sample Type: Disturbed

Seive Size (mm) | Passing %
---|---
50.8 | 100.0
38.1 | 100.0
25.4 | 100.0
19.00 | 100.0
12.7 | 100.0
9.51 | 100.0
4.75 | 100.0
2.00 | 100.0
1.19 | 100.0
0.425 | 99.9
0.297 | 99.7
0.149 | 43.5
0.075 | 17.5

Sample Type: Disturbed

 BH-4 Depth: 10.0 meter

Tested by: Asif Imran

Checked by: Muhammad Ajmal

Approved by: Engr. Farooq Naveed
Grain Size Analysis

Project: Conservation, Rehabilitation and Sustainable Development of Walled City Lahore
(Geotechnical Investigations for Wazir Khan's Mosque)

Client: Aga Khan Cultural Services, Pakistan  
Lab Ref.: J 488/L-018/09  
Date: 28/09/2009

BH-5  
Depth: 8.0 meter  
Sample No: UDS-1  
Sample Type: Undisturbed

Tested by: Asif Imran  
Checked by: Muhammad Ajmal  
Approved by: Engr. Farooq Naveed
Grain Size Analysis

Project: Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

Client: Aga Khan Cultural Services, Pakistan

Lab Ref.: J 488/L-018/09

Date: 28/09/2009

BH-5 Depth: 10.0 meter

Sample No.: SPT-2

Sample Type: Disturbed

Seive Size (mm) | Passing % age
---|---
50.8 | 100.0
38.1 | 100.0
25.4 | 100.0
19.00 | 100.0
12.7 | 100.0
9.51 | 100.0
4.75 | 100.0
2.00 | 99.7
1.19 | 99.5
0.425 | 99.2
0.297 | 99.0
0.149 | 68.3
0.075 | 32.0

Tested by: Asif Imran
Checked by: Muhammad Ajmal
Approved by: Engr. Farooq Naveed
Grain Size Analysis

Project: Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)

Client: Aga Khan Cultural Services, Pakistan  Lab Ref.: J 488/L-018/09  Date: 28/09/2009

BH-6  Depth: 7.0 meter  Sample No: SPT-4  Sample Type: Disturbed

Tested by: Asif Imran  Checked by: Muhammad Ajmal  Approved by: Engr. Farooq Naveed
# APPENDIX C

## Grain Size Analysis

<table>
<thead>
<tr>
<th>Seive Size (mm)</th>
<th>Passing % age</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.8</td>
<td>100.0</td>
</tr>
<tr>
<td>38.1</td>
<td>100.0</td>
</tr>
<tr>
<td>25.4</td>
<td>100.0</td>
</tr>
<tr>
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</tr>
<tr>
<td>0.149</td>
<td>68.5</td>
</tr>
<tr>
<td>0.075</td>
<td>30.1</td>
</tr>
</tbody>
</table>

*Seive Size: mm, Passing % age.*

---

**Sample Details:**

- **Sample:** BH-6
- **Depth:** 10.0 meter
- **Sample Type:** Disturbed
- **Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan’s Mosque)
- **Client:** Aga Khan Cultural Services, Pakistan
- **Lab Ref.:** J 488/L-018/09
- **Date:** 28/09/2009
- **Sample No:** SPT-7
- **Approved by:** Engr. Farooq Naveed

---

**Graph:**

- Average Grain Diameter (mm)
- Percentage Passing (%)

---

**Legend:**

- Boulder
- Cobbles
- Gravel
- Sand (Coarse, Medium, Fine)
- Silt
- Clay
### Appendix C

**Borehole No. BH-2**
Depth: 7.5 Meter
Sample No. UDS-2
Lab Ref. J 488/L-018/09

<table>
<thead>
<tr>
<th>Unit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test No.</td>
<td>40</td>
<td>29</td>
<td>16</td>
<td>29</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Water content %</td>
<td>33.15</td>
<td>30.05</td>
<td>49.99</td>
<td>42.11</td>
<td>35.83</td>
<td>42.26</td>
</tr>
<tr>
<td>Moisture content %</td>
<td>3.04</td>
<td>2.9</td>
<td>7.03</td>
<td>5.1</td>
<td>2.95</td>
<td>2.87</td>
</tr>
<tr>
<td>Wt. of dish+wet soil</td>
<td>28.3</td>
<td>29.1</td>
<td>29.8</td>
<td>30.7</td>
<td>18.6</td>
<td>18.8</td>
</tr>
</tbody>
</table>

**Note:**

- Description: Liquid Limit
  - Water content %: 30%
- Plastic Limit
  - Plasticity Index: 11%
  - Group of soil: A-6

---

**Borehole No. BH-3**
Depth: 7.5 Meter
Sample No. UDS-1
Lab Ref. J 488/L-018/09

<table>
<thead>
<tr>
<th>Unit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test No.</td>
<td>35</td>
<td>29</td>
<td>24</td>
<td>19</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Water content %</td>
<td>33.15</td>
<td>30.05</td>
<td>49.99</td>
<td>42.11</td>
<td>35.83</td>
<td>42.26</td>
</tr>
<tr>
<td>Moisture content %</td>
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<td>2.9</td>
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<td>5.1</td>
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<td>18.6</td>
<td>18.8</td>
</tr>
</tbody>
</table>

**Note:**

- Description: Liquid Limit
  - Water content %: 30%
- Plastic Limit
  - Plasticity Index: 11%
  - Group of soil: A-6

---

**Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)
**Client:** Aga Khan Cultural Services, Pakistan
**Date:** 26/09/2009

**Tested by:** Asif Imran
**Checked by:** Ajmal Malik
**Approved by:** Engr. Farooq Naveed

---

**Berkeley Associates**

**Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils**

- **Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)
- **Client:** Aga Khan Cultural Services, Pakistan
- **Date:** 26/09/2009
- **Borehole No.: BH-2**
- **Sample No.: UDS-2**
- **Lab Ref.: J 488/L-018/09**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Water content %</th>
<th>Moisture content %</th>
<th>Wt. of dish+wet soil</th>
<th>Wt. of dish+dry soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33.15</td>
<td>3.04</td>
<td>28.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30.05</td>
<td>2.9</td>
<td>29.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>49.99</td>
<td>7.03</td>
<td>29.8</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>42.11</td>
<td>5.1</td>
<td>30.7</td>
<td></td>
</tr>
</tbody>
</table>

---

**Berkeley Associates**

**Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils**

- **Project:** Conservation, Rehabilitation and Sustainable Development of Walled City Lahore (Geotechnical Investigations for Wazir Khan's Mosque)
- **Client:** Aga Khan Cultural Services, Pakistan
- **Date:** 26/09/2009
- **Borehole No.: BH-3**
- **Sample No.: UDS-1**
- **Lab Ref.: J 488/L-018/09**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Water content %</th>
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<th>Wt. of dish+wet soil</th>
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<tr>
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<td>42.11</td>
<td>5.1</td>
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<td></td>
</tr>
</tbody>
</table>

---

**Tested by:** Asif Imran
**Checked by:** Ajmal Malik
**Approved by:** Engr. Farooq Naveed
APPENDIX - D

FIELD PHOTOGRAPHS

Floor tiles being preserved for preparation of circulation pit for drilling

Borehole being drilled in cultural fill by light percussion drilling method
Borehole being drilled in natural soil deposit by straight rotary drilling method

Cultural fill samples being preserved

Natural soil SPT sample being preserved
Borehole being backfilled with cement bentonite slurry

A view of excavated testpit showing steps of minaret foundation

Conservation, Rehabilitation and Sustainable Development of Walled City Lahore
Factual Report on Geotechnical Investigations for Wazir Khan’s Mosque
The spectacular monumental ensemble of the Wazir Khan Mosque in the Walled City of Lahore was built in 1634 during the reign of the Mughal emperor Shah Jahan. Its endowment then comprised the congregational mosque, an elaborate forecourt, a serai, a hammam, a bazaar, and a special bazaar for calligraphers and bookbinders. The mosque, the calligraphers' bazaar, and the hammam still stand, while the other elements have disappeared—victims to Lahore's turbulent history over nearly four centuries since the original dedication. What remains is increasingly in need of care and attention.

Over a two year period starting in 2009, the Historic Cities Programme of the Aga Khan Trust for Culture, through the Aga Khan Cultural Service - Pakistan, conducted a baseline documentation of the monument and its surrounding areas. This volume contains the results of this work and presents an assessment of the organisational, technical and financial requirements for the conservation of the mosque as well as the revitalisation and enhancement of its surrounding context.

The Trust has been actively engaged with the Punjab Government in the conservation of the urban fabric of the Walled City of Lahore and, since 2007, collaborated in urban rehabilitation and infrastructure improvement efforts in the neighbourhood of the monument.